AIR TRAFFIC CONCEPT UTILIZING 4D TRAJECTORIES AND AIRBORNE SEPARATION ASSISTANCE

Thomas Prevot*, Vernol Battiste, Everett Palmer and Stephen Shelden*

*San Jose State University,
NASA Ames Research Center
Moffett Field, CA 94035

Contents

Introduction

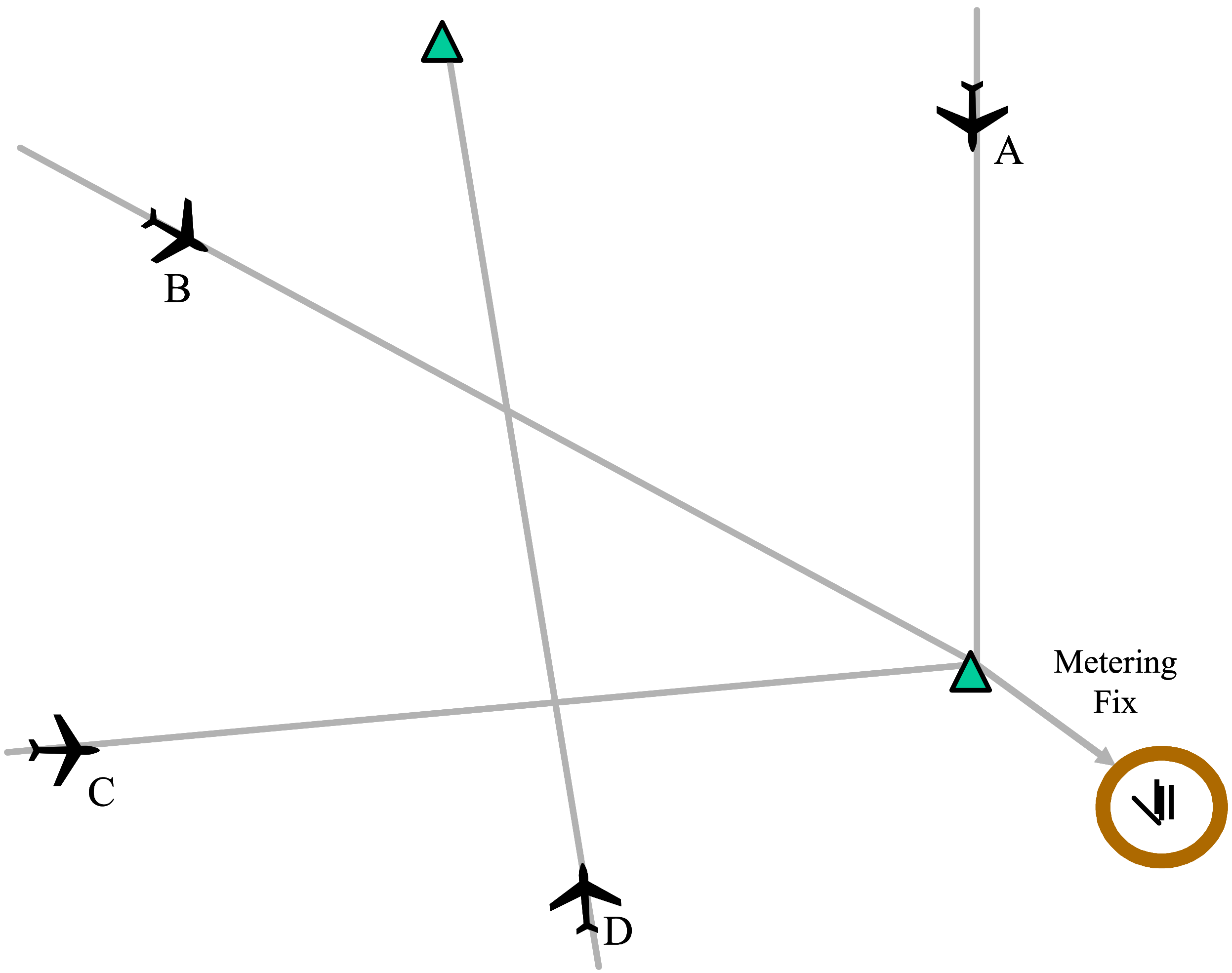
- Today’s tactical “sector-oriented” air traffic control:
  - Safe
  - Can cause inefficiencies
  - Limited by controller workload and frequency congestion

- Different approaches to address the inefficiencies and limitations
  - 4D Trajectory-based approaches (strategic)
  - Use of Airborne Separation Assistance Systems (ASAS) (tactical)

- Proposal:
  - Combine both approaches to achieve “the best of both worlds”*

*Graham, R., E. Hoffmann, C. Pusch, and K. Zeghal, 2002, *Absolute versus Relative Navigation: Theoretical Considerations from an ATM Perspective*, e.g. ATM 2003

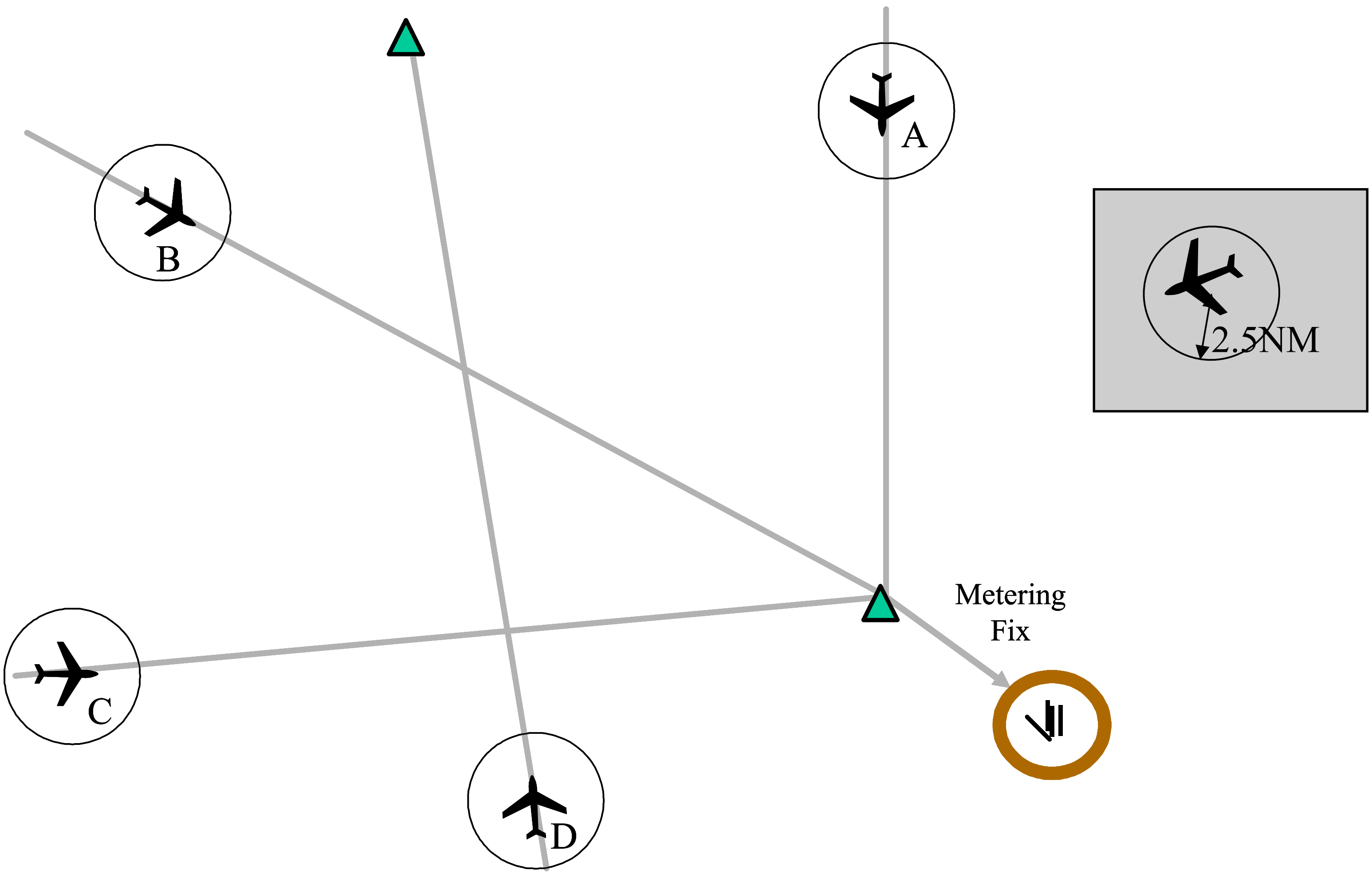
Example Traffic Problem



The three arrivals A, B, and C merge at a metering fix, the over flight D crosses the path of arrival B and C

Assume lateral separation has to be achieved

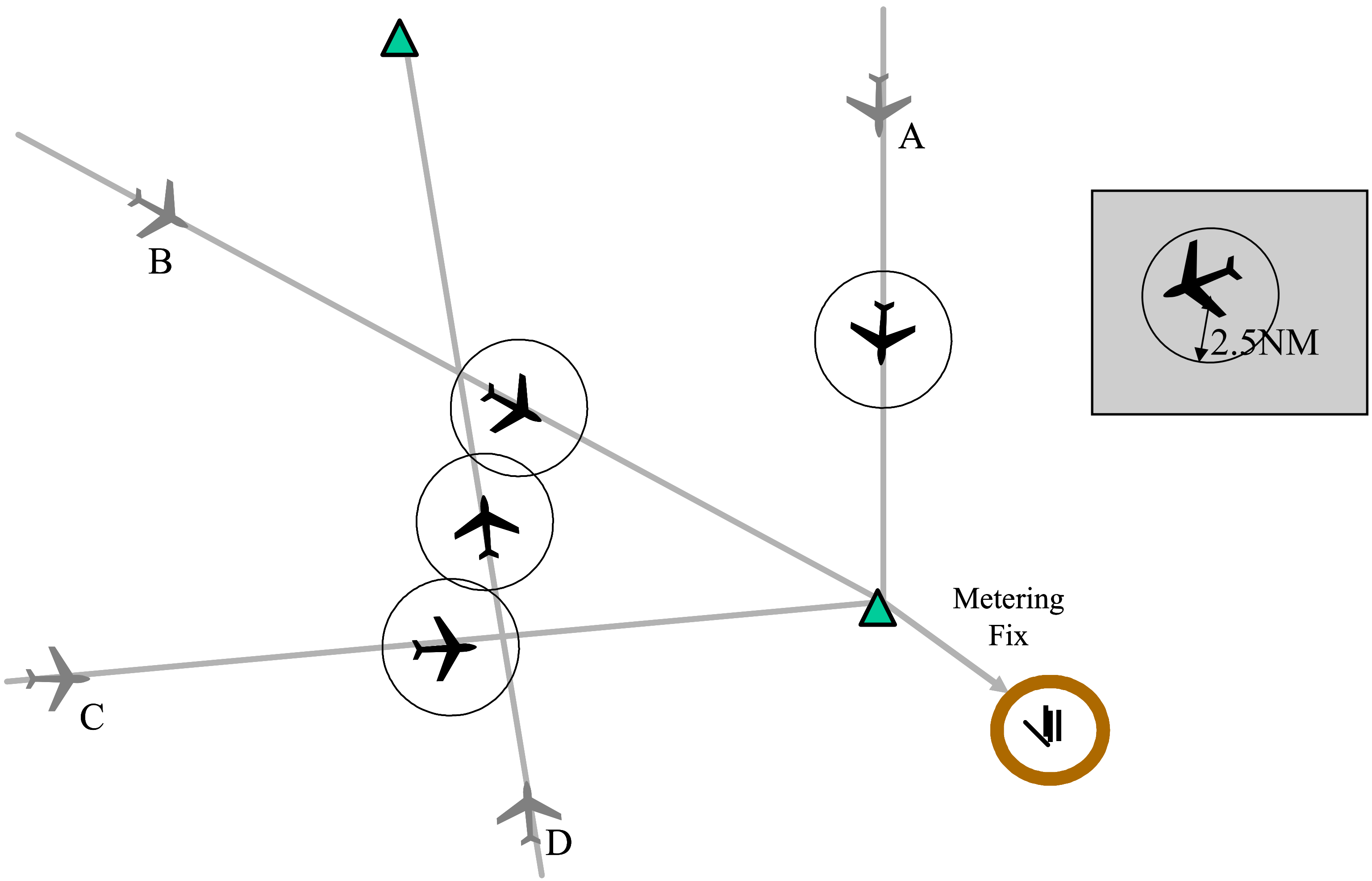
Example Traffic Problem



Strategy:

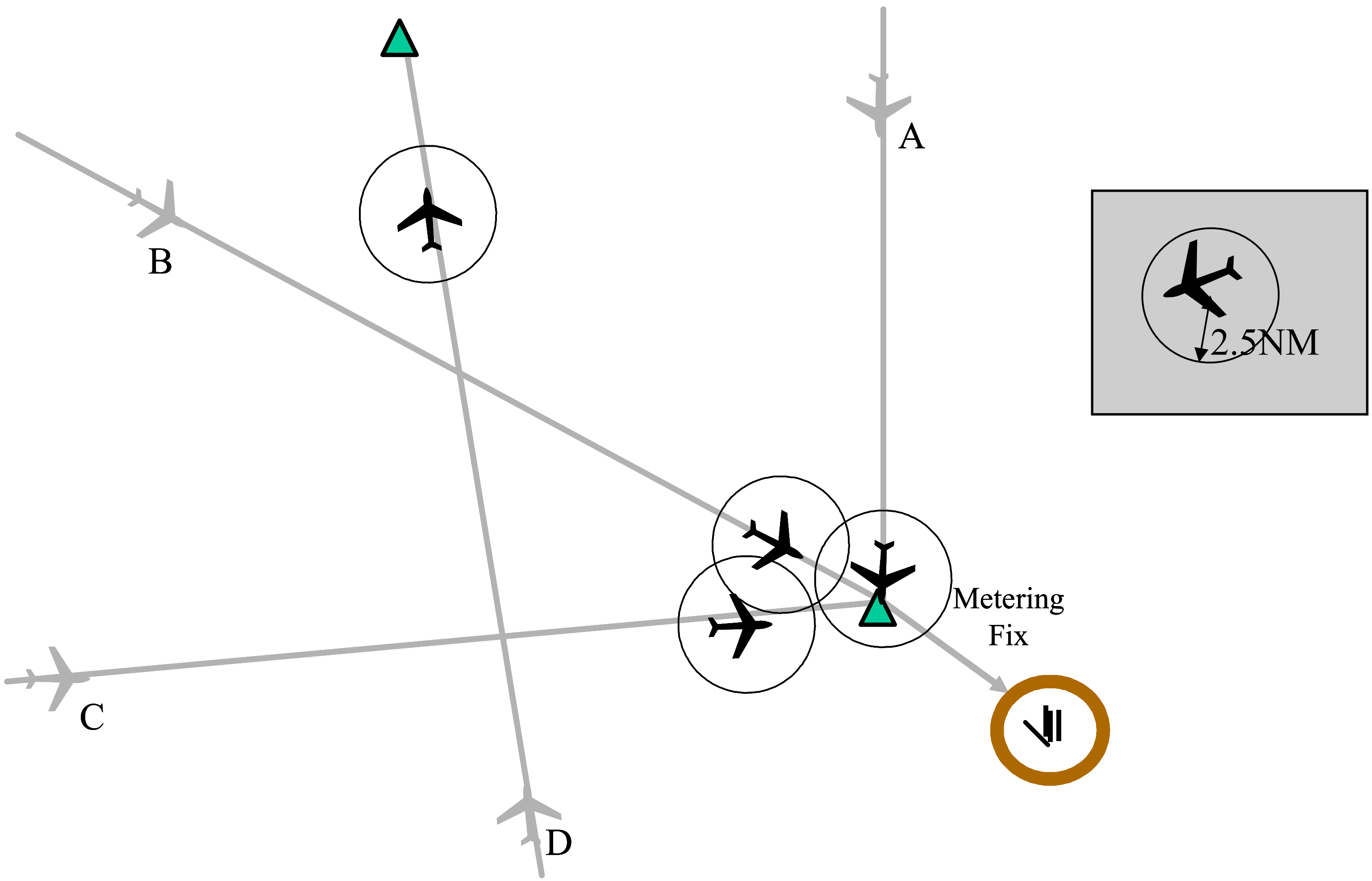
Let the aircraft follow their flight paths with no intervention

Example Traffic Problem



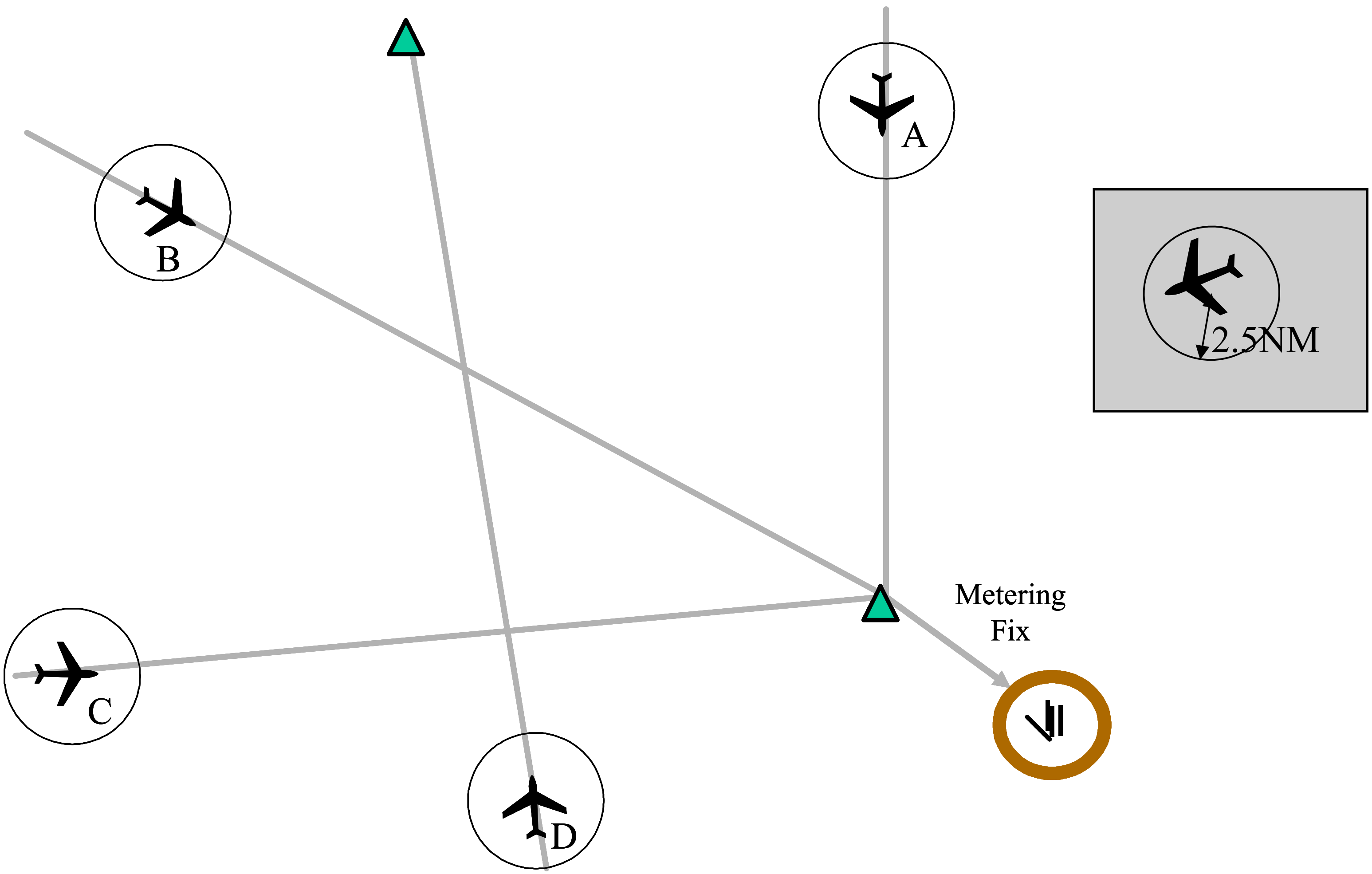
The over flight D gets too close to the arrivals B and C.

Example Traffic Problem



The arrivals A, B, and C arrive at the metering fix at almost the same time.

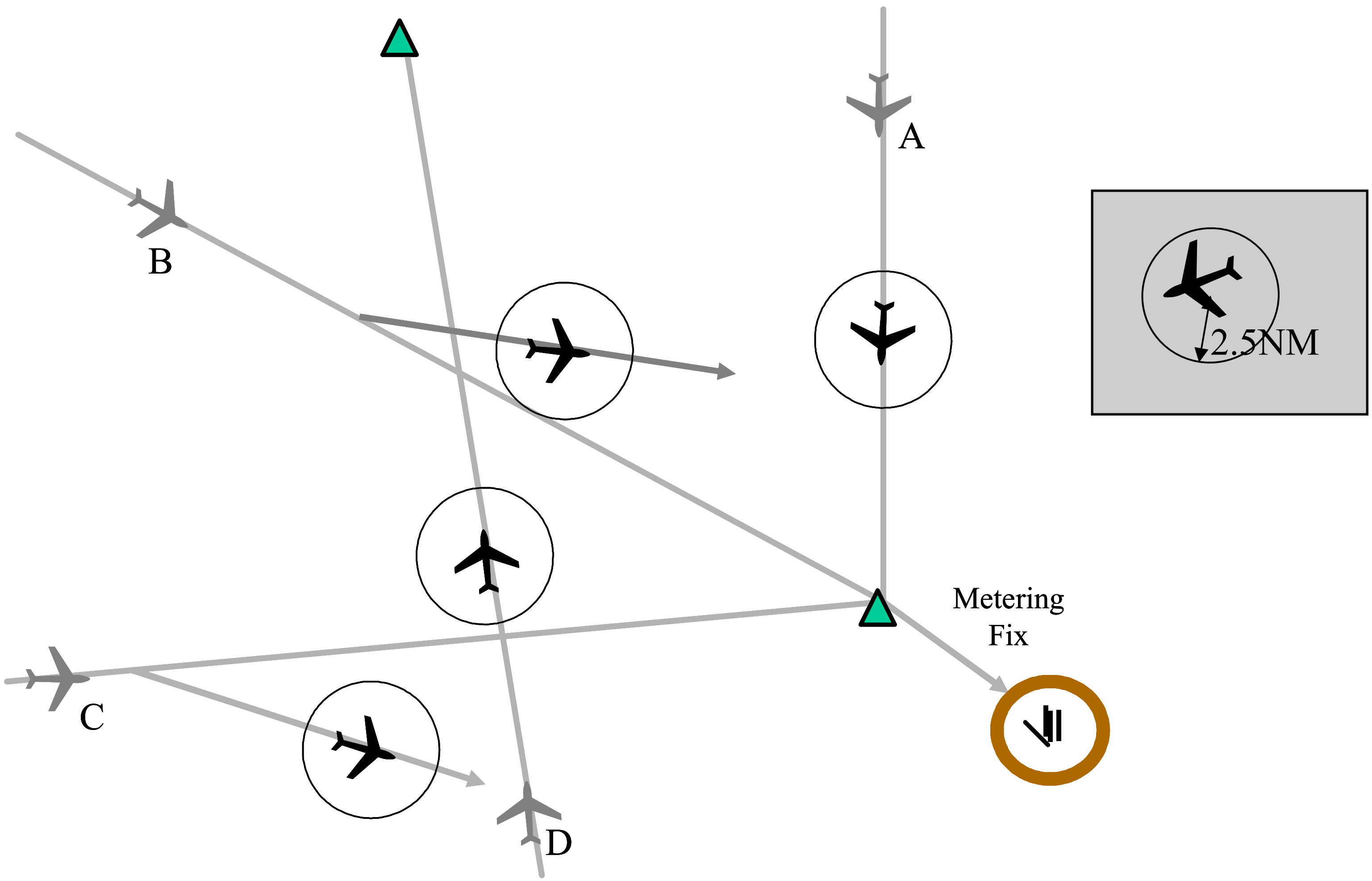
Tactical Sector Based Operations



Strategy:

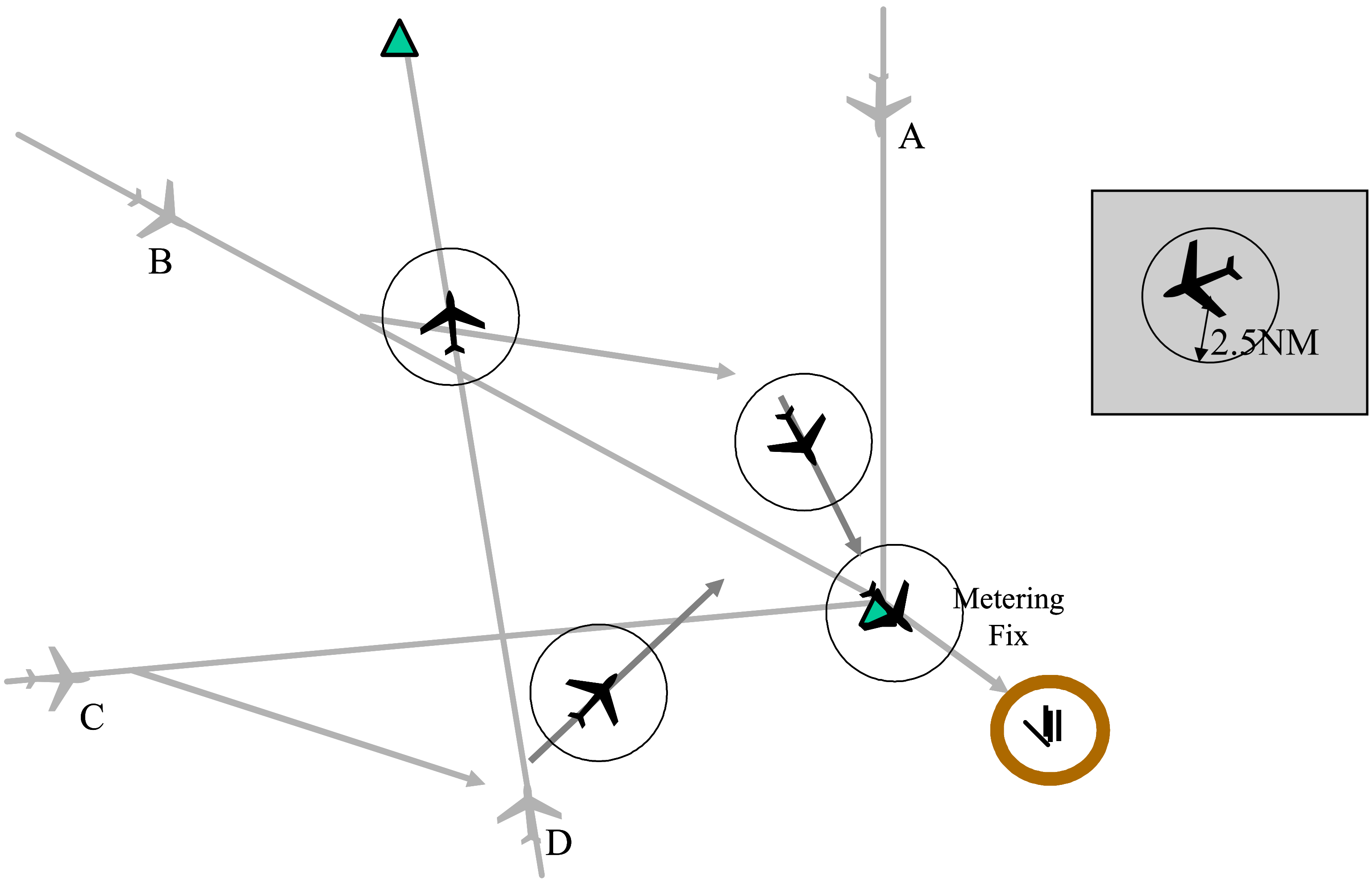
Issue heading vectors that separate over flight D from arrivals B and C and absorb the delay required to meet the metering constraints of A, B, and C at the metering fix.

Tactical Sector Based Operations



The heading vectors are designed to provide clear flight paths for a certain amount of time and may be excessive. The controller needs to monitor the situation to issue the next vectors at the appropriate time.

Tactical Sector Based Operations

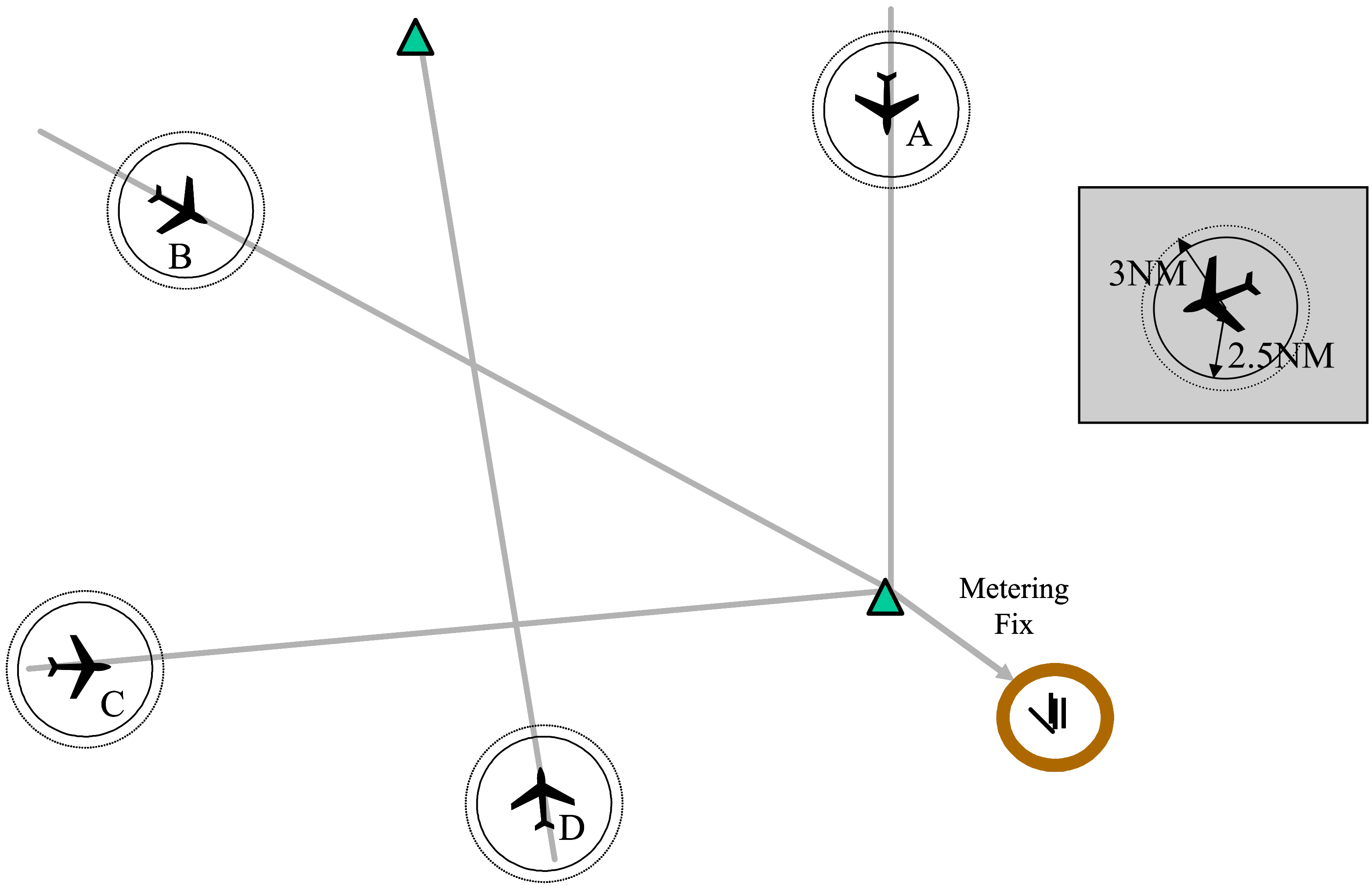


New heading vectors and further monitoring is required to manage the merge.

ASAS and Limited Delegation

- E.g Eurocontrols CoSpace, NASA's DAG-TM CE-11
- Uses aircraft-to-aircraft relative operations without changing separation assurance responsibility
- Utilizes Airborne Separation Assistance Systems (ASAS) to
  - improve flight crew situation awareness
  - Increase controller availability through a better allocation of tasks between the air and the ground (*Hoffman, Zeghal* …)
- Some benefits
  - Addresses local separation and provides for good safety margins
  - Introduces redundancy into the separation assurance process
  - Enables efficient local conflict resolution strategies
  - May reduce controller workload
- Some shortcomings
  - No global traffic flow strategy
  - Reduced predictability of flight paths, if not along standard trajectories
  - Controllers need to tactically direct aircraft to a proper position from which the goal of the limited delegation clearance is achievable (can be done in the same clearance "*heading then merge*")

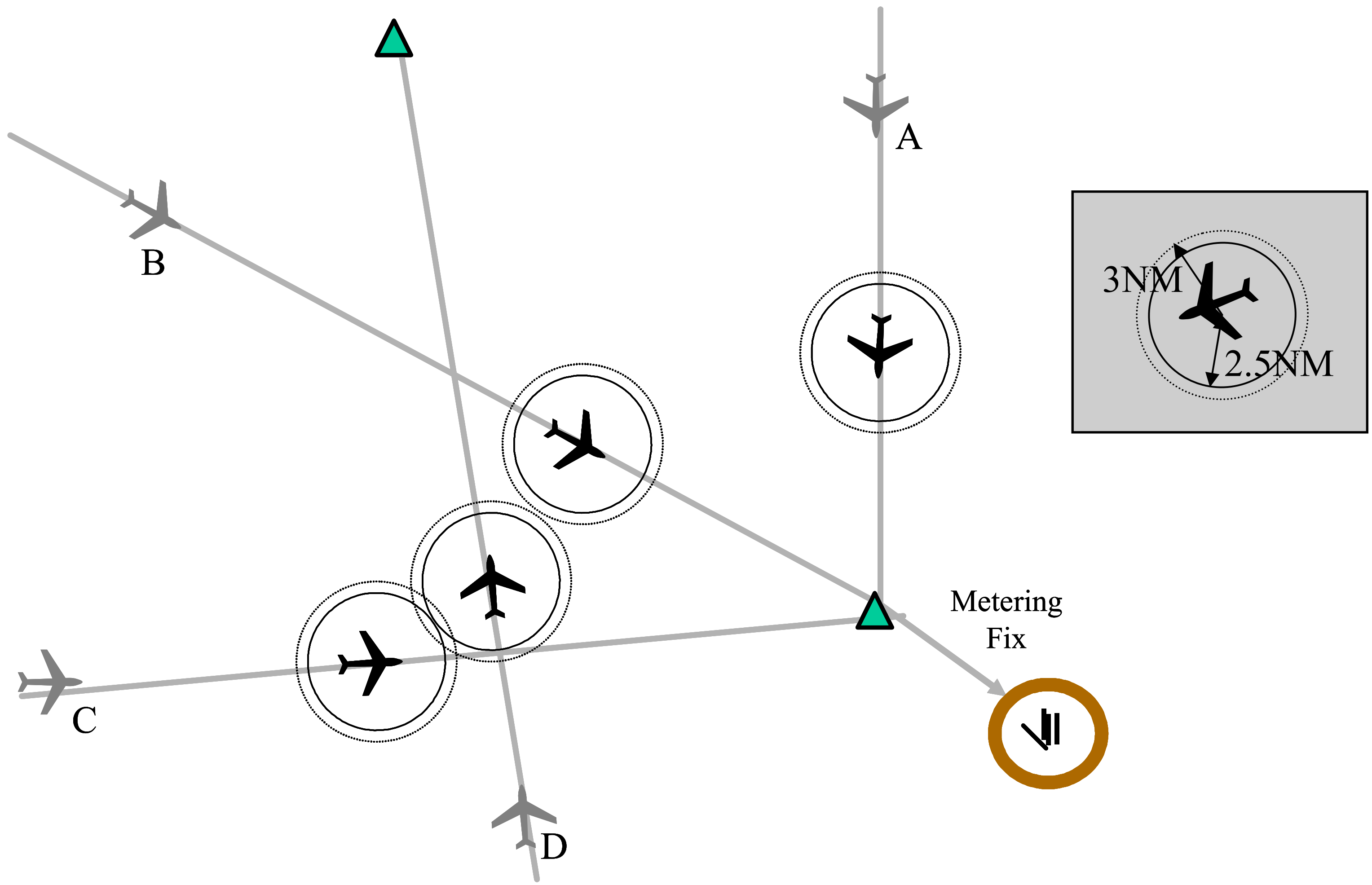
ASAS and Limited delegation: Only Speed Changes



Strategy:

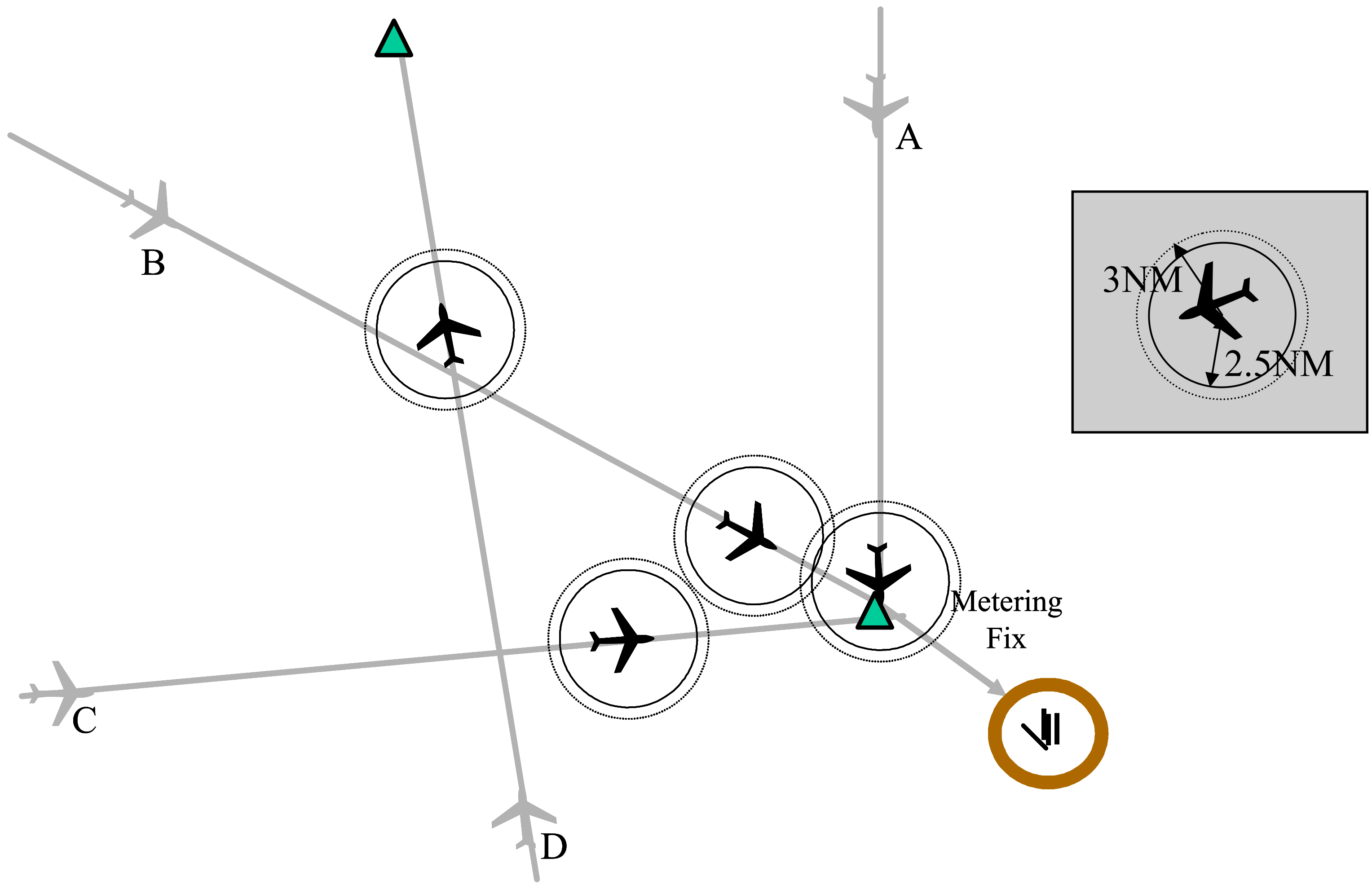
Delegate the spacing tasks to the flight crew, using only speed changes to achieve the desired spacing

ASAS and Limited delegation: Only Speed Changes



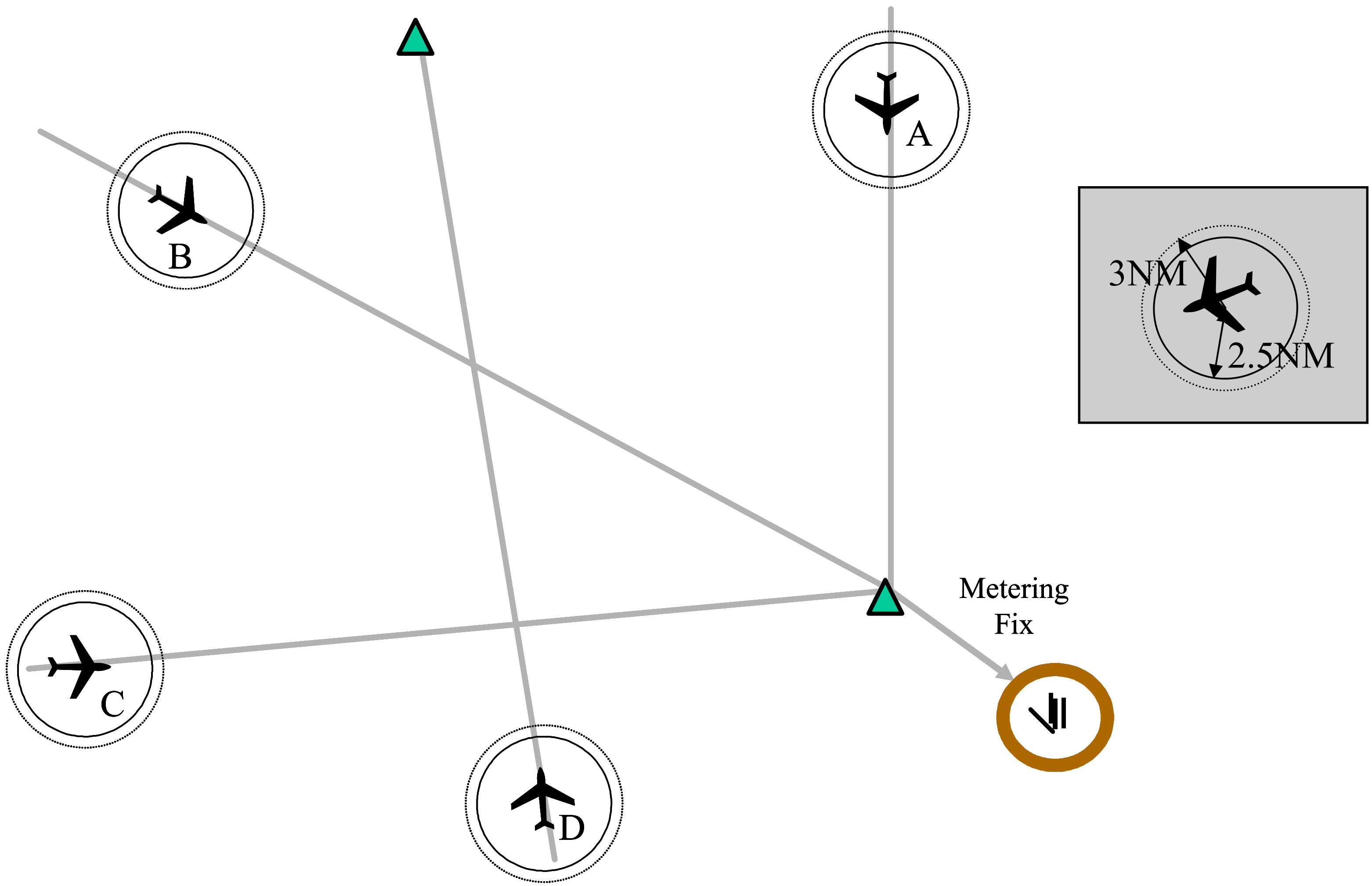
Speed control is insufficient to separate the over flight D from the arrivals C and B.

ASAS and Limited delegation: Only Speed Changes



Speed control is also insufficient to achieve the required separation between the arrivals A, B, and C at the merge point.

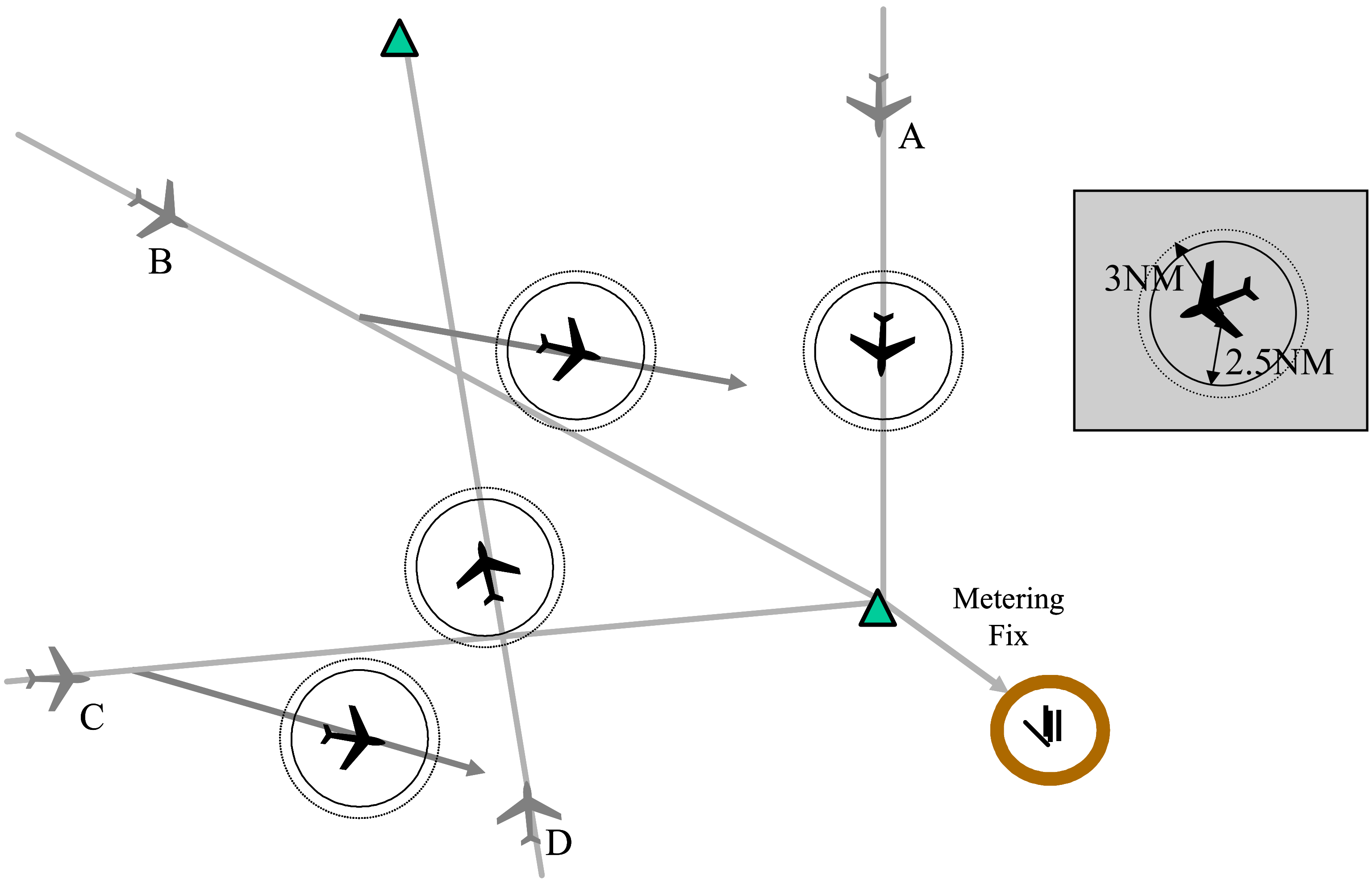
ASAS and Limited delegation: Vectoring and Speed Changes



Strategy:

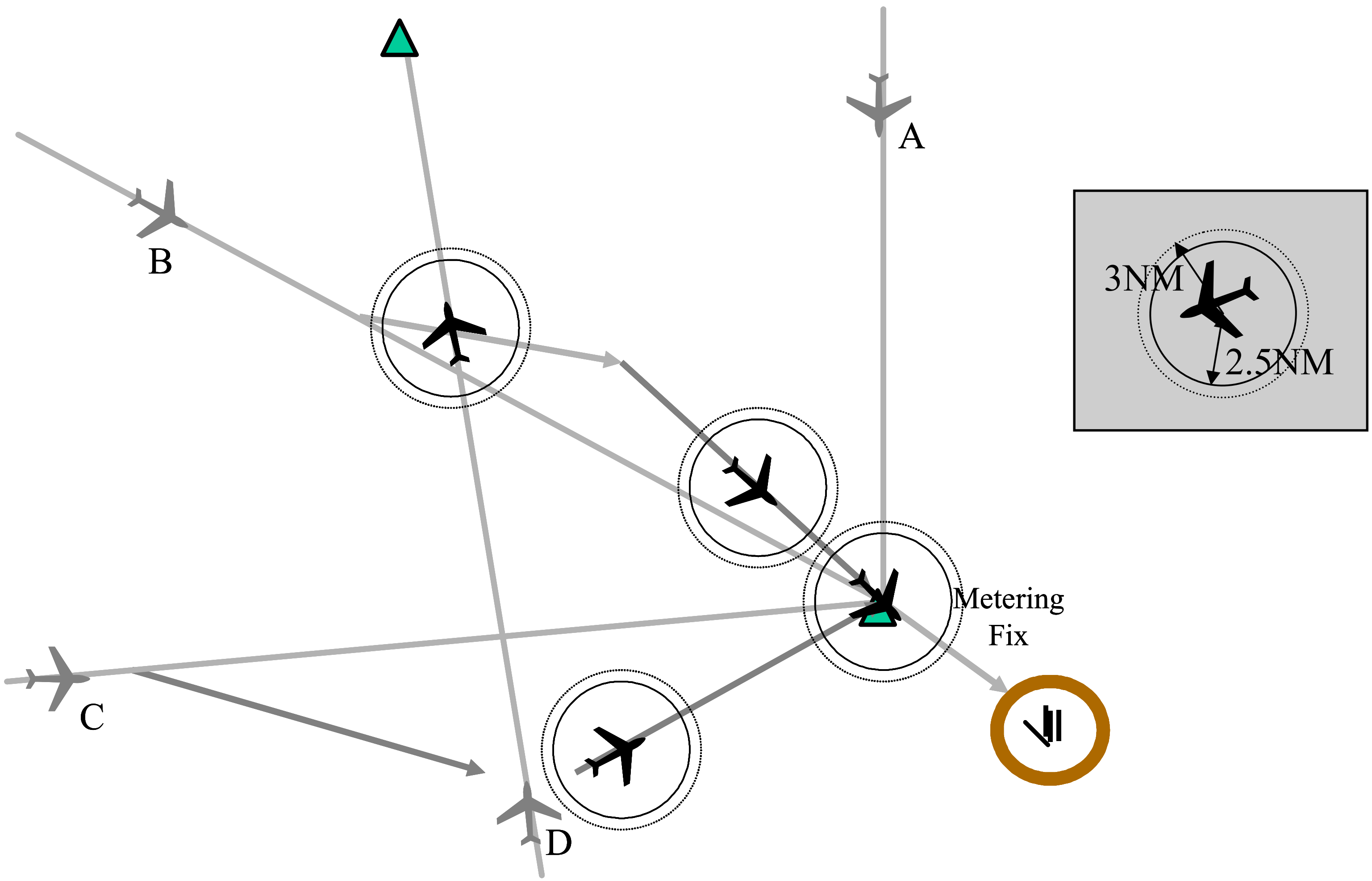
Issue heading vectors that separate over flight D from the arrivals A and C and put the flight crews into a position to achieve the desired spacing with only speed control. Then delegate the spacing tasks to the flight crew.

ASAS and Limited Delegation: Vectoring and Speed Changes



The over flight – arrival conflict is likely to be handled with heading vectors.
Monitoring is required to turn the aircraft back.

ASAS and Limited delegation: Vectoring and Speed Changes



The aircraft can be turned back directly to the metering fix and the spacing task delegated. Once the flight crew manages the spacing, no further instructions should be necessary and the monitoring task is simplified for the controller.

4D Trajectory-Based Operations

- E.g. PHARE, AFAS, CTAS, DAG-TM CE5 and CE6
- Approach relies on accurate trajectory prediction capabilities
- Supports
  - Air traffic management tasks like traffic flow management, scheduling and runway balancing
  - Air traffic control tasks like conflict detection and metering
- Increases flight path predictability
- Computationally, a ***near*** optimal set of de-conflicted trajectories, taking into account AOC preferences and TFM constraints can be generated
- Practical execution of these optimal trajectories faces a number of operational challenges, including:
  - Uncertainties in the trajectory prediction due to unknown conditions and input parameters not factored in
  - Human factors issues for controllers and flight crews in modifying, communicating, and monitoring trajectories under time pressure
  - Imprecise execution of clearances on the flight deck by flight crews or flight management automation systems

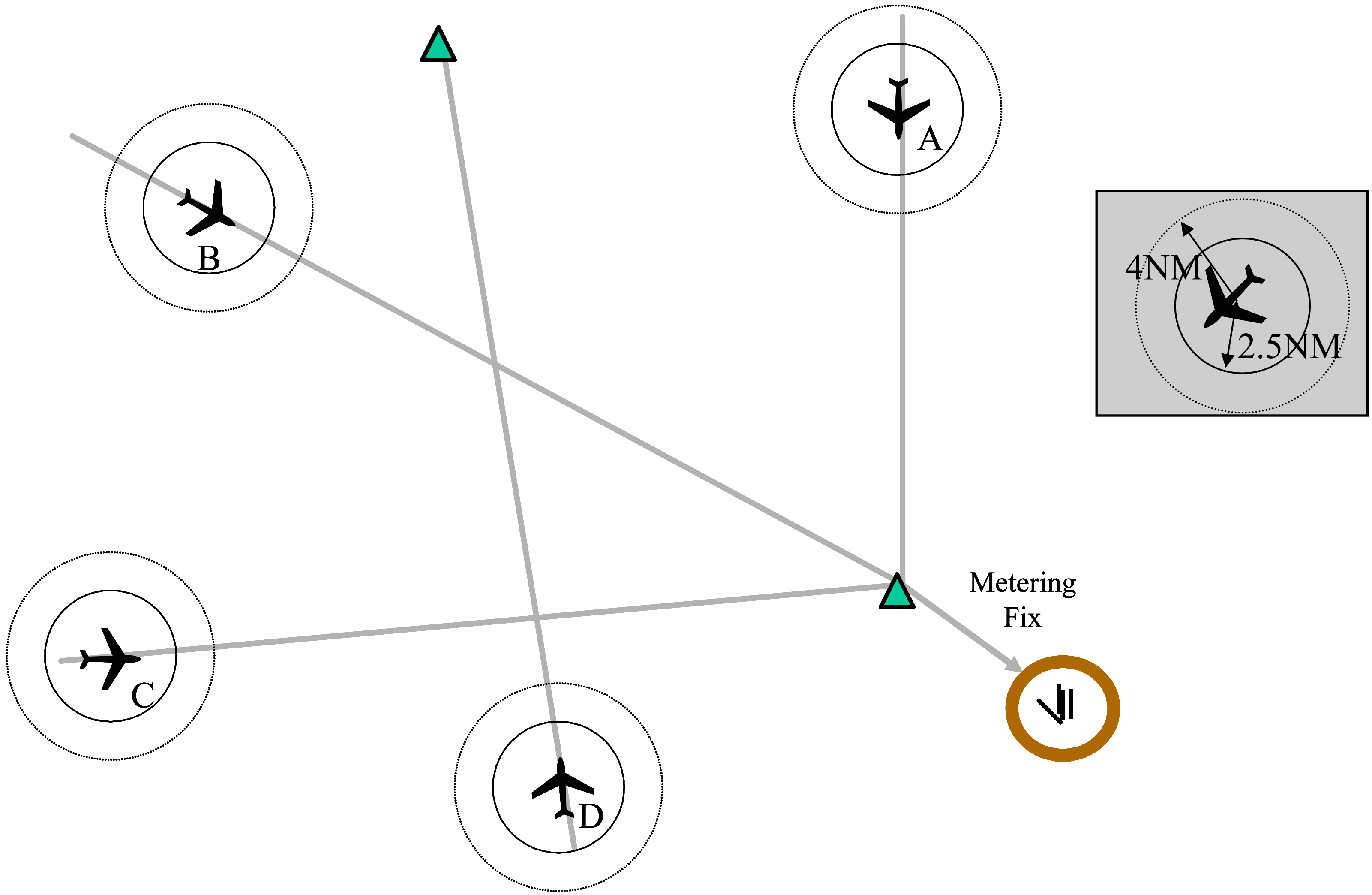
4D Trajectory-Based Operations : DAG-Results

- DAG-TM experiments in 2002 at NASA Ames Research Center compared two trajectory-based experimental conditions (CE5 “free maneuvering” and CE6 “En route trajectory negotiation”) to a current day metering control condition.

- 4D trajectory-based operations resulted in:
  - A significant reduction in the variance of the inter-arrival spacing at the metering fix; indicating that aircraft were delivered more consistently
  - More efficient descent paths, i.e. many aircraft were able to remain longer at a higher altitude, and then flew uninterrupted idle descents
  - Reduced sector controller workload at the low altitude position, which is responsible for merging aircraft at the meter fix
  - No workload increase in the high altitude feeder positions, which set up the trajectories for the low altitude position
  - Better (self-reported) performance by the controllers than in a current day control condition

- The main problems encountered in this experiment were:
  - Trajectory de-confliction along the paths to the metering fix
  - Usability of some of the ground automation tools, especially the responsiveness of the trial planning tool that the controllers used to generate new trajectories

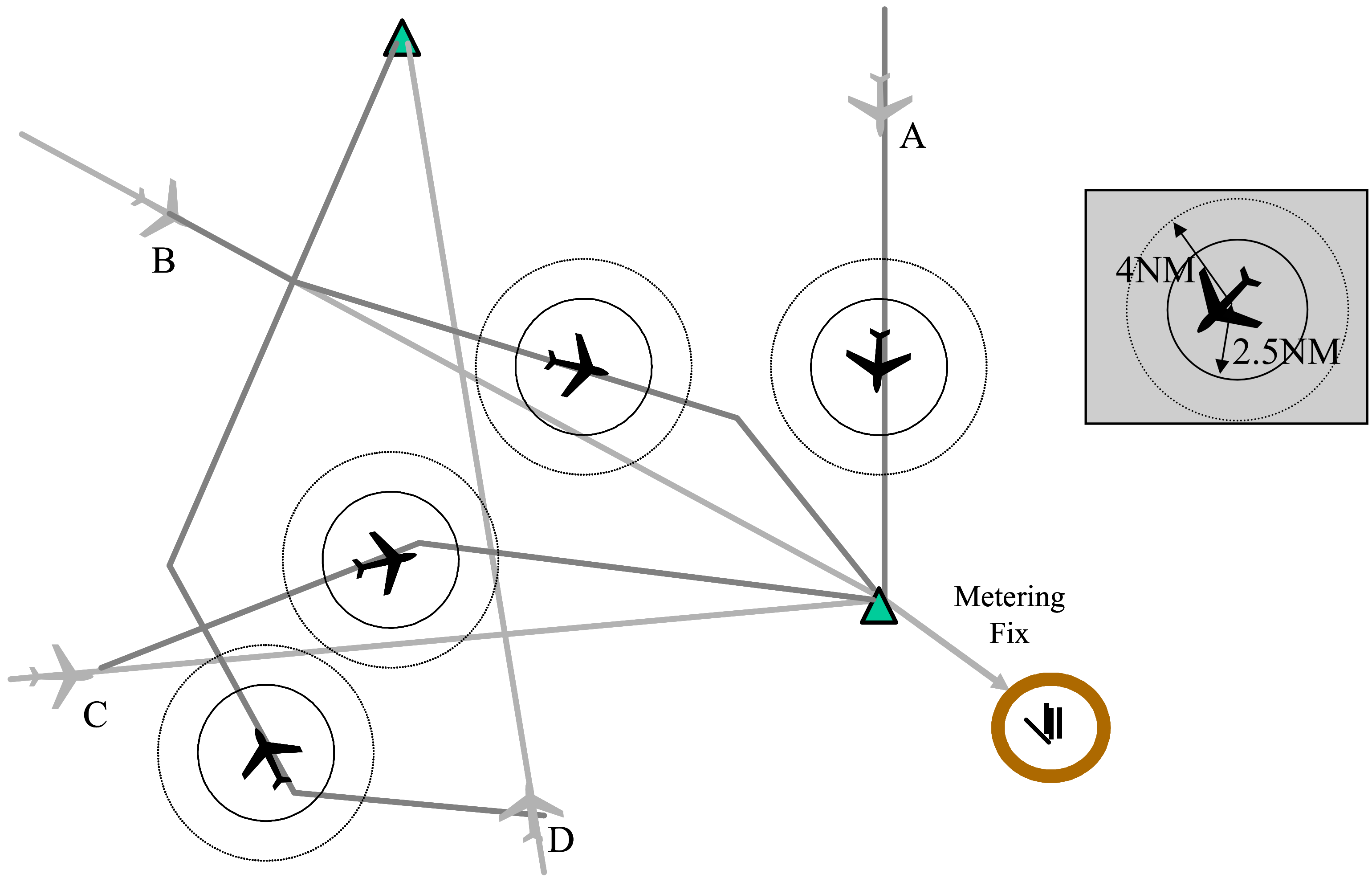
4D Trajectory-Based Operations



Strategy:

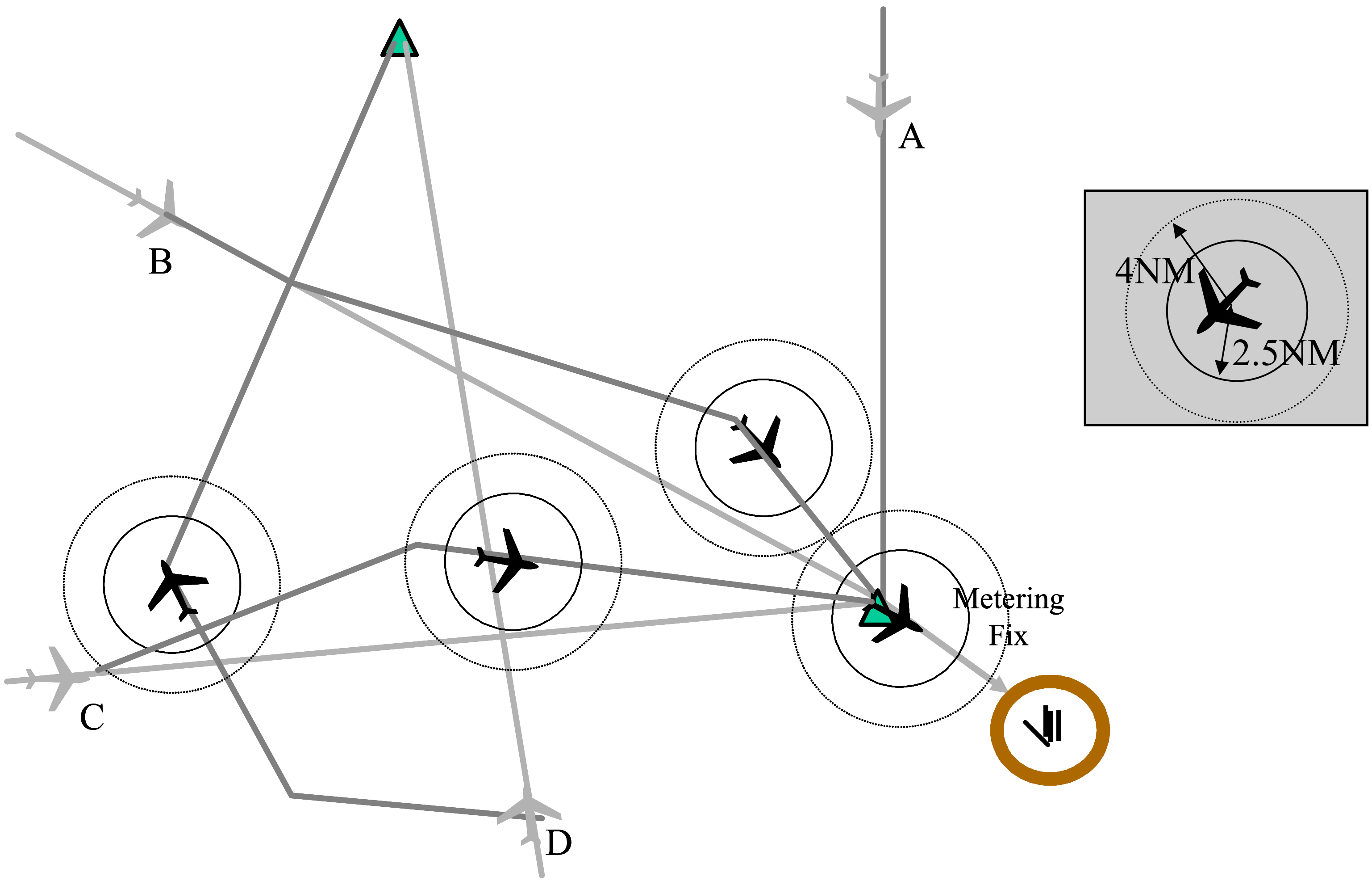
Generate a set of conflict free trajectories with “bigger than necessary” buffers for prediction uncertainty that meet the metering constraints and communicate the trajectory change points to the flight crew.

4D Trajectory-Based Operations



The extra buffers to accommodate the prediction uncertainty limit the number of possible solutions and reduce the available airspace. However, the trajectories can be designed to meet the metering constraints precisely.

4D Trajectory-Based Operations



The metering constraints need to be defined such that enough separation is provided even if the aircraft deviate slightly from their trajectories. Otherwise, the controller still needs to issue late instructions for safety.

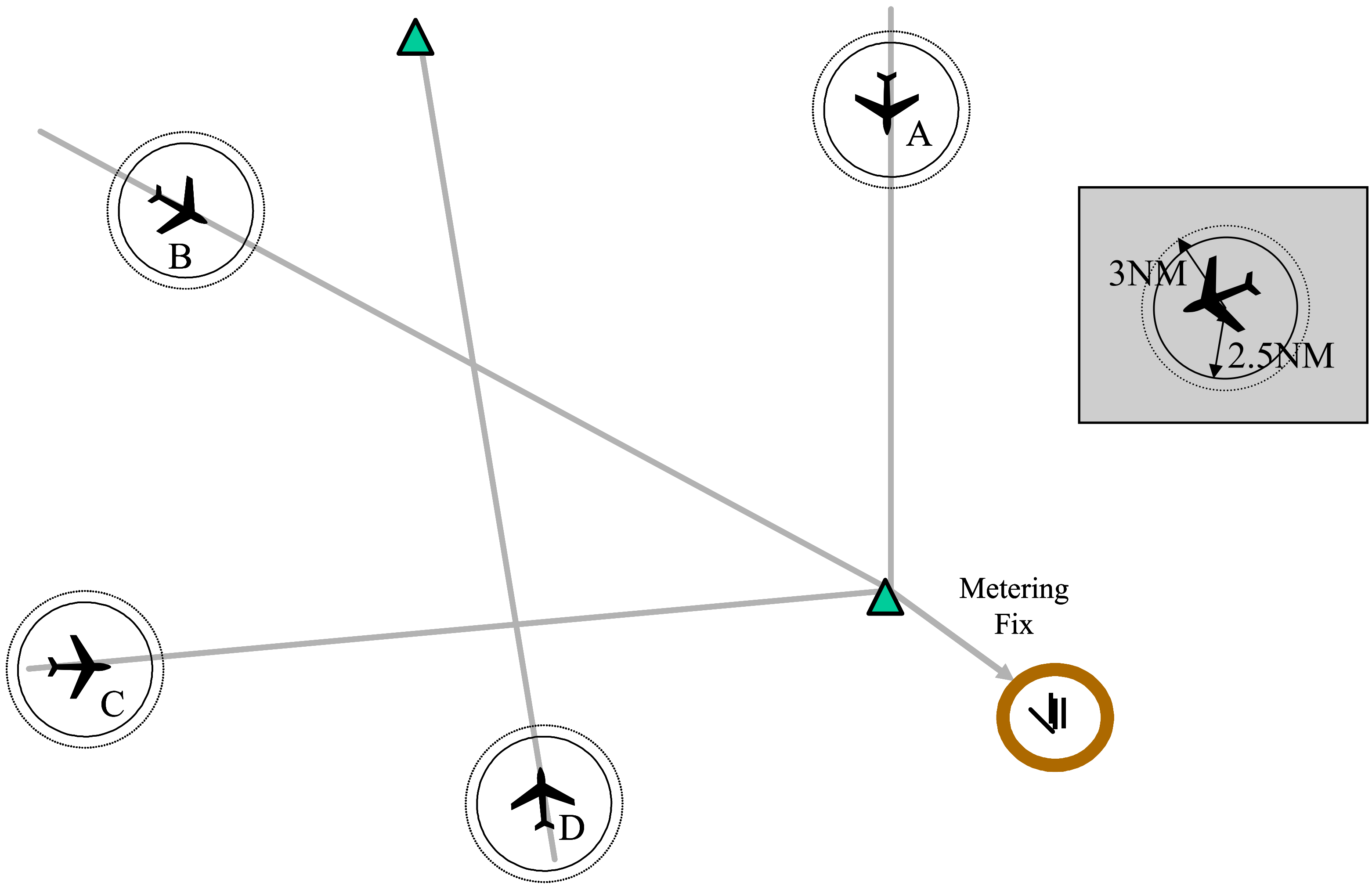
Concept

- *Use trajectory-based operations to create efficient, nominally conflict-free trajectories that conform to traffic management constraints and,*

- *maintain local spacing between aircraft with airborne separation assistance*

Envisioned Benefits

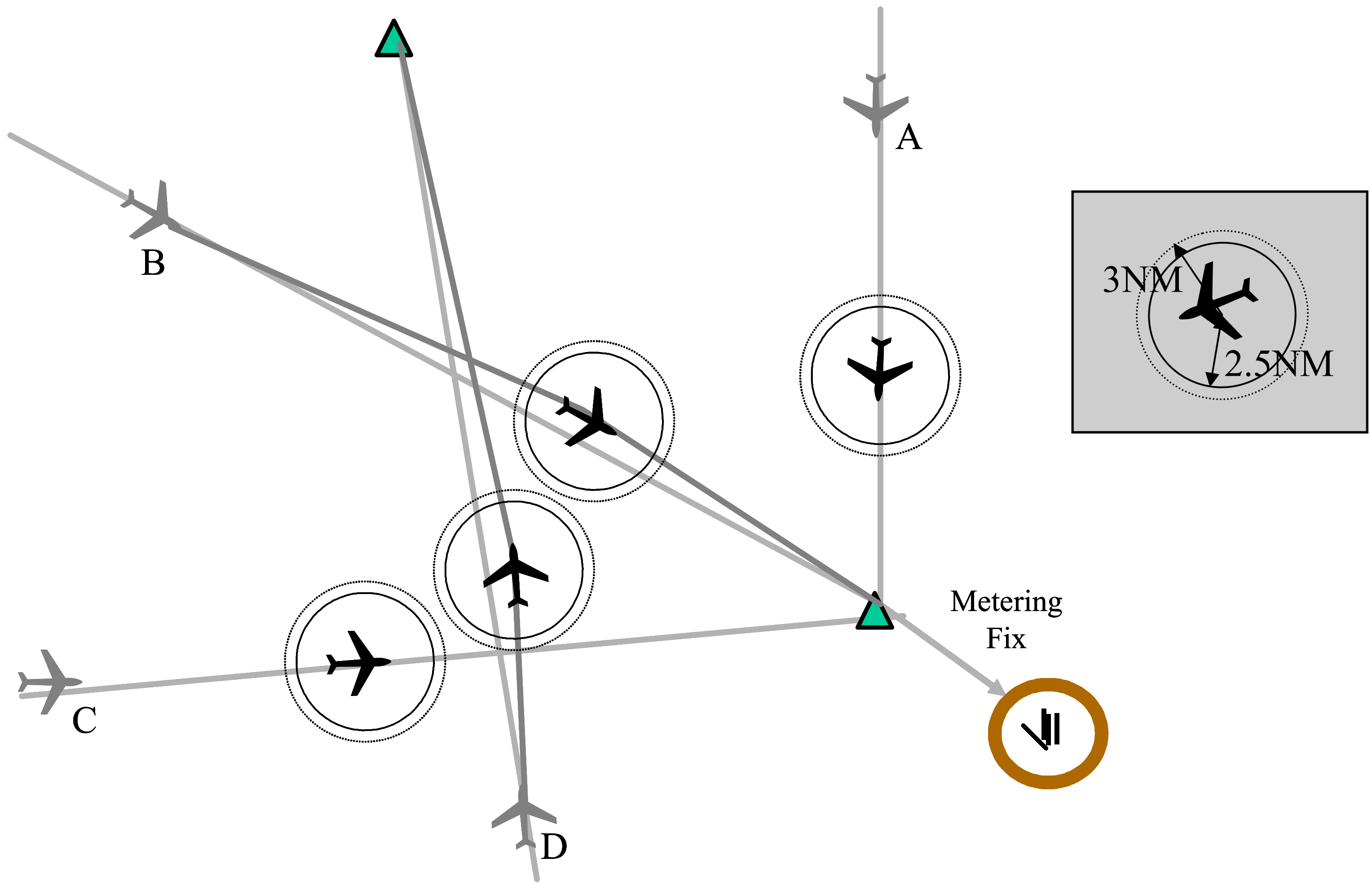
- Take full advantage of the traffic flow management benefits of the trajectory-oriented approach
- Reduce to a minimum any additional conflict resolution buffers arising out of prediction uncertainty
- Reduce controller workload → increase controller availability
- Minimally impact flight crew workload.
- Have a positive effect on controller and flight crew traffic awareness
- Limit the deviations from the 4D path to short-term deviations mostly due to speed changes, thereby minimizing the medium to long-term prediction uncertainty
- Minimize lateral route and/or altitude changes for local separation assurance



Strategy:

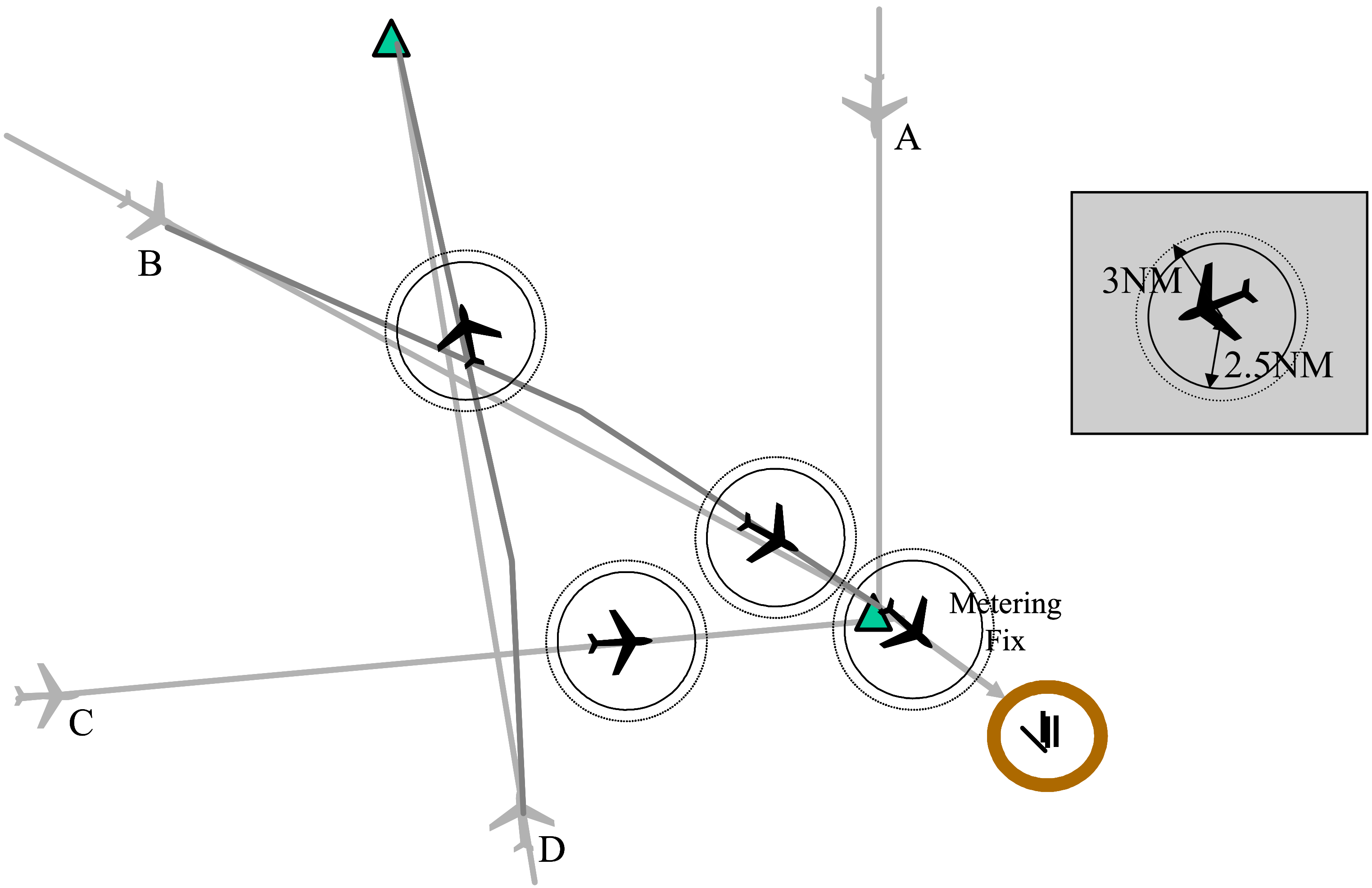
Generate a set of conflict free trajectories with small buffers for flight deck based spacing inaccuracies that meet the metering constraints, communicate the trajectory change points to the flight crew and delegate the spacing tasks to the flight crew.

Trajectory Oriented Operations with Limited Delegation



The trajectories can be designed with minimal buffers to precondition the aircraft properly and meet the metering constraints precisely. The spacing will be fine-tuned by the flight crew dynamically.

Trajectory Oriented Operations with Limited Delegation

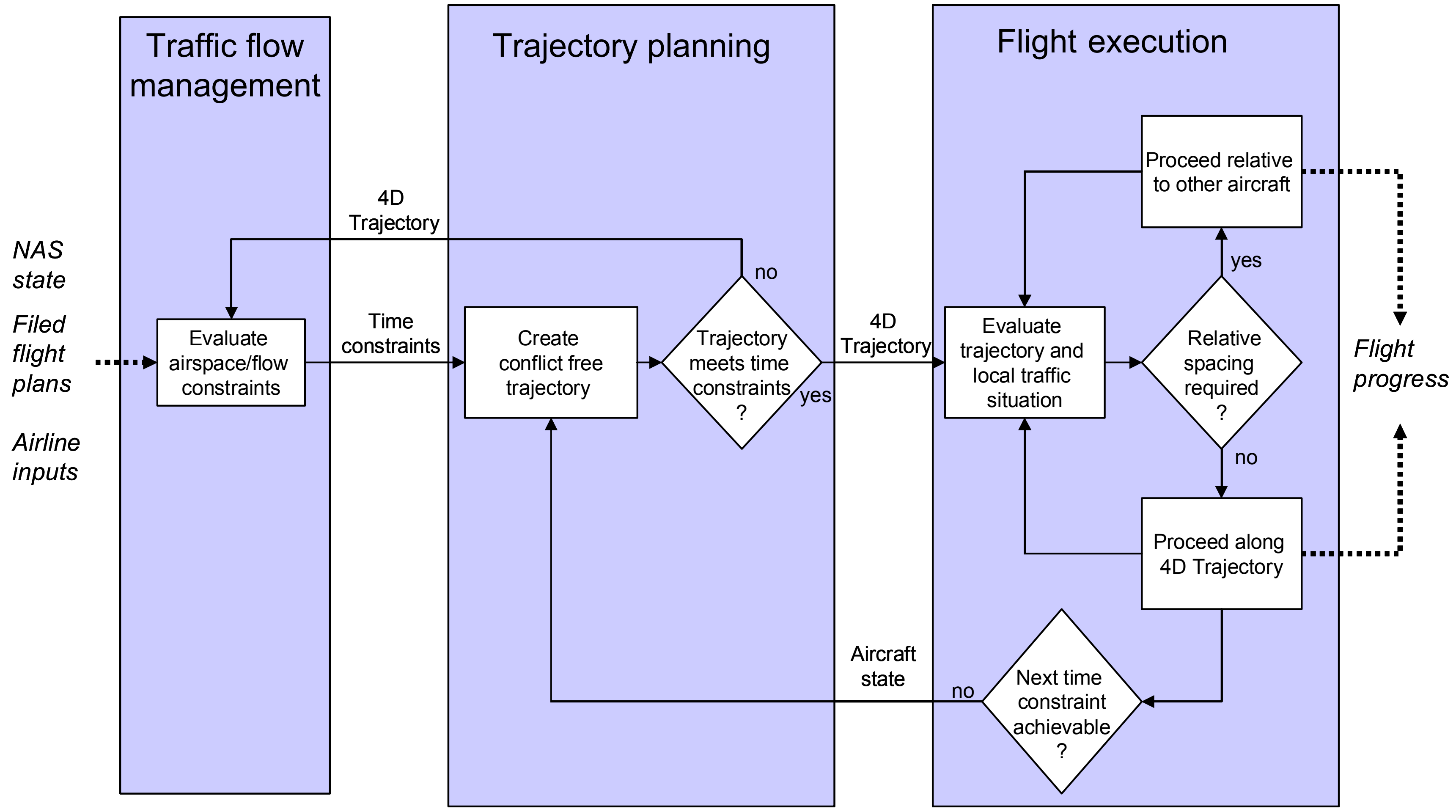


The metering constraints can be defined with minimal separation buffers and the aircraft handle the merge and follow each other into the next airspace (e.g. TRACON)

Trajectory Oriented Operations with Limited Delegation

AATT

Interaction between TFM, trajectory planning and flight execution for proposed concept*



*Prevot T., S. Shelden, J. Mercer, P. Kopardikar, E. Palmer and V. Battiste (2003) *ATM Concept Integrating Trajectory-Orientation and Airborne Separation Assistance in the Presence of Time-based Traffic Flow Management*, DASC 2003, Indianapolis, in preparation

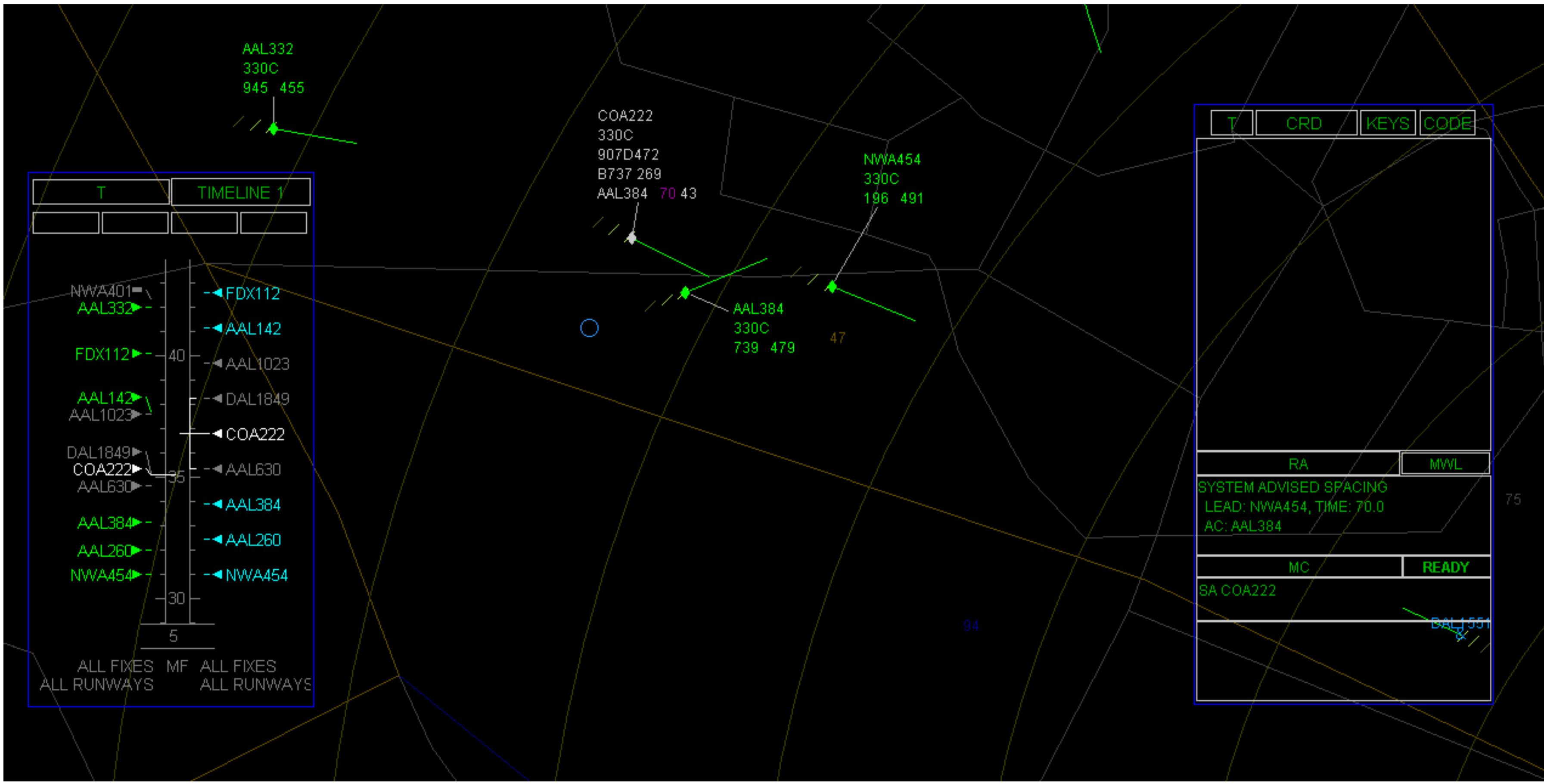
Concept Implementation

- Near-term:
  - Ground-side:
    - Trajectory tools
    - Conflict detection tools
    - Could use standard trajectories (airways, STARs, approach transitions)
    - Simple spacing assignment and monitoring function
  - Air-side
    - Improved surveillance e.g. ADS-B
    - Traffic display
    - Simple state-based spacing algorithm

- Medium to Far-term
  - Ground-side:
    - CD&R tools
    - Trajectory negotiation capabilities (e.g. integrated CPDLC)
  - Air-side
    - Trajectory tools
    - CDTI with CD&R capabilities
    - Trajectory negotiation capabilities (e.g. integrated CPDLC)
    - Advanced self spacing capabilities (local free maneuvering)

Concept Implementation: Ground side example

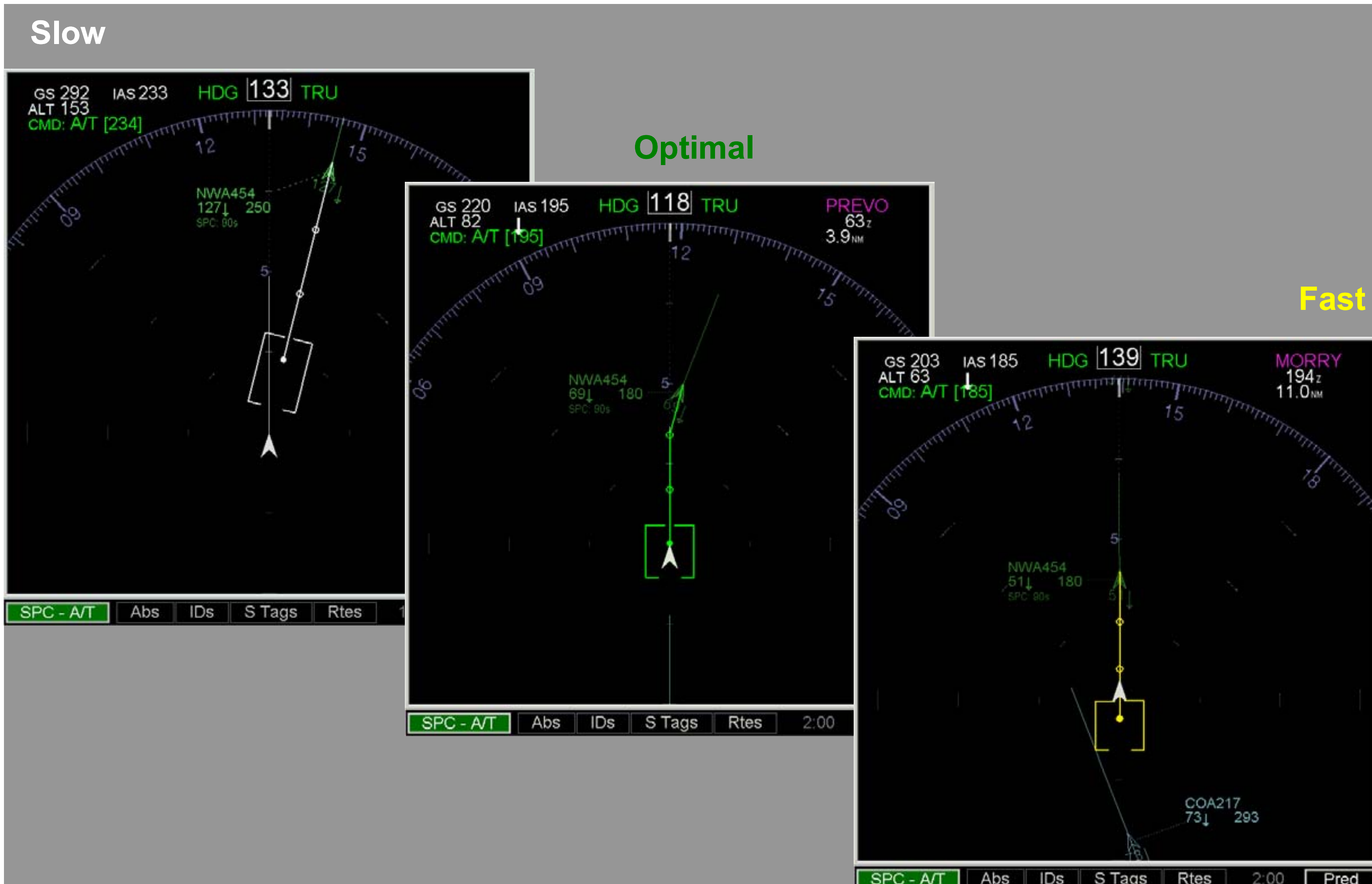
Mock-up of a display system replacement (DSR) center controller display with trajectory information on timeline and spacing information in data tag and aircraft history circle



Concept Implementation: Air side example

Flight deck display prototype indicating the ownship position relative to the desired spacing position (historical position of the lead aircraft 90 seconds ago)

The advised speed command is displayed in the upper left corner



Concluding Remarks

The concept:

Use trajectory-based operations to create efficient, nominally conflict-free trajectories that conform to traffic management constraints and, maintain local spacing between aircraft with airborne separation assistance.

- Integrates two promising approaches
- Shows a potential for maintaining high safety *and* improving efficiency over today's system
- Can be implemented evolutionarily, and an immediate paradigm shift by air traffic controllers and pilots is not required
- Can build on existing tools and strategies, can provide immediate and emergent benefits, and is compatible with advanced DAG-TM concepts
- The benefits of trajectory-based operations can be realized *without* having to generate completely de-conflicted routes with 'buffers' for prediction uncertainty
- Flight crews monitoring 'local' situations in *addition* to ground controllers, is a further level of operational safety – a second set of eyes

- Research is required and planned to further develop and evaluate this concept

Acknowledgements

NASA Ames Research Center:

- Nancy Smith, Todd Callantine, Paul Lee, Joey Mercer, Walt Johnson
- The Flight Deck Research Group
- Sandy Lozito and her research team
- Dave Encisco and the AOL support staff
- the MACS development team
- the ACFS support staff

Richard Mogford and NASA’s AATT project office

the Air Line Pilots Association

the National Air Traffic Controllers Association

the FAA’s Air Traffic Services office